

# DEMONSTRATION REPORT

Demonstration of Advanced Geophysics and Classification  
Technologies on Munitions Response Sites  
Fort Rucker, Alabama

ESTCP Project MR-201161

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## ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DERP	Defense Environmental Restoration Program
DGM	Digital Geophysical Mapping
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
ID	Identification
IDA	Institute for Defense Analyses
IMU	Inertial Measurement Unit
IVS	Instrument Verification Strip
LM	Library Matching
MEC	Munitions and Explosives of Concern
MM	MetalMapper
MMRP	Military Munitions Response Program
MRS	Munitions Response Site
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Nfa	Number of False Alarms
Pclass	Probability of Correct Classification of TOI
QC	Quality Control
RFI	RCRA Facility Inspection
RTK	Real-Time Kinematic
SARA	Superfund Amendments and Reauthorization Act
SI	Site Inspection
TOI	Target of Interest
URS	URS Group, Inc.
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

## **1.0 INTRODUCTION**

This document serves as the Environmental Security Technology Certification Program (ESTCP) Demonstration Report for the Demonstration of Advanced Geophysics and Classification Technologies in various areas of the Munitions Response Site (MRS) at Fort Rucker, Alabama. This project is one in a series of projects funded by ESTCP to test the effectiveness of advanced geophysical sensors and physics-based data analysis tools for anomaly classification.

The project purpose is to interrogate anomalies acquired using traditional geophysical sensors (e.g., EM61-MK2) with MetalMapper (MM) and the advanced data analysis method contained in UX-Analyze in a production environment to characterize various areas of the Silver Wings Golf Course Complex at Fort Rucker, Alabama.

### **1.1 BACKGROUND**

ESTCP contracted URS Group, Inc. (URS) to utilize MM in dynamic survey mode to map golf course fairways and in cued mode in the project Demonstration Area. URS processed and demonstrated the use and performance of an advanced anomaly classification method using the MM data.

### **1.2 OBJECTIVE OF THE DEMONSTRATION**

Digital geophysical mapping (DGM) of former military ranges results in the identification and location of subsurface anomalies at a site. Typically, very small fractions of these anomalies are munitions and explosives of concern (MEC). The majority of these anomalies are harmless metallic objects (e.g., munitions fragments, small arms projectiles, range-related debris, or cultural debris). ESTCP and other collaborators have developed advanced electromagnetic induction sensors and geophysical data processing methods that have proven effective at classifying subsurface metallic objects as either targets of interest (TOI) (i.e., objects having the size, shape, and wall thickness associated with MEC) or non-targets of interest (non-TOI) (i.e., harmless scrap metal). This demonstration serves to:

- Demonstrate the cost and performance of these sensors and methods on increasingly challenging MRSs,
- Train Military Munitions Response Program (MMRP) contractors on the application of these sensors and methods to facilitate technology transfer and industry-wide adoption, and
- Identify opportunities for potential improvement of the sensors and classification methods.

### **1.3 REGULATORY DRIVER**

The ESTCP Live Site Demonstrations are executed under the guidance of the Department of Defense (DoD) MMRP, which is a portion of the Defense Environmental Restoration Program (DERP). DERP is the DoD program to execute environmental response consistent with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA); the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations 300); and Executive Order 12580, Superfund Implementation.

## **2.0 TECHNOLOGY**

### **2.1 TECHNOLOGY DESCRIPTION**

The Geometrics MM was used to collect data in cued mode to provide data for advanced analysis to determine whether each geophysical anomaly previously identified using an EM61-MK2 resulted from a TOI. Additional dynamic survey mode data were also collected and processed, but not analyzed by URS. The inverted MM data were analyzed to classify anomalies as TOI or non-TOI using the Library Matching (LM) protocols contained within the UX-Analyze extension to Geosoft's Oasis Montaj. The MM was custom mounted on a fork attachment to a skid-steer, tracked bobcat by URS to minimize damage to the golf course that might have occurred using other tow platforms.

#### **2.1.1 Advanced Geophysical Data Collection**

##### **2.1.1.1 Dynamic Survey Mode**

The MM system was demonstrated in dynamic survey mode in Fairway #6 (approximately 4.4 acres). The MM was mounted on a fork attachment to a skid-steer, tracked bobcat with the monitor attached to the interior of the bobcat. Positioning was provided by a Real-Time Kinematic (RTK) Global Positioning System (GPS) mounted above the center of the array. The MM dynamic data were processed into "flat files" with each receiver sounding assigned an X and Y location and loaded into Oasis Montaj for basic quality control (QC) checks.

##### **2.1.1.2 Cued Mode**

The MM system was used to collect cued data on 407 anomalies in the Demonstration Area, 377 anomalies in Fairway #1, 430 anomalies in Fairway #6, and 137 anomalies in Fairway #9.

#### **2.1.2 Anomaly Classification Methods**

URS applied the LM tool within UX-Analyze to classify anomalies as TOI and non-TOI from the MM cued data. Anomalies were classified into three categories:

- Category 0: Cannot analyze
- Category 1: Likely TOI
- Category 2: Cannot decide (not used)
- Category 3: Likely non-TOI

The Geosoft UX-Analyze software package was used to process and invert the data for polarizability. Inversion results were classified using LM. Three separate requests for training data were made, and an initial dig list was submitted that contained no QC failures (detected all of the seed items). A final, revised list was submitted using the initial dig list results as additional training data.

Details of the classification methodology are described in Section 6.

## **2.2 TECHNOLOGY DEVELOPMENT**

MM is a commercially-available advanced data acquisition platform that can be used in cued and dynamic acquisition modes. LM is an algorithm included in the UX-Analyze plug-in to Oasis Montaj.

Previous experience with MM revealed safety issues using the tractor-mounted platform recommended by the instrument developer. The long, leverage arm of the tow platform tends to destabilize the tractor on sloped terrain, especially where numerous ruts are present. Because the Fort Rucker MRS is a golf course, concerns were raised about potential damage to the golf course from a heavy, wheeled tow vehicle. To resolve these concerns, URS developed a custom mount onto a tracked bobcat with a forklift attachment with sufficient weight rating to maintain stability in the area of planned operations.

To analyze the cued data, URS used the LM algorithm to match against a library of known responses to TOI. Targeted anomalies were grouped into clusters based on the TOI response that most closely matched in the library. Samples from each cluster were chosen as training data. Any TOI identified in the training data were added into the library of known TOI. In clusters where at least one TOI was identified, additional targeted anomalies were selected as training data to determine whether and where the quality of the match determined whether an item might be a TOI. High quality matches to TOI identified in previous training data were also selected for the next round of training data. This process was repeated until the analyst believed all TOI in the dataset were identified. For this project, three rounds of training were requested.

## **2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY**

### **2.3.1 Dynamic Data Collection with MetalMapper**

The ability to collect a single geophysical dataset that allows munitions response project teams to identify and distinguish individual anomalies and subsequently classify each anomaly as a TOI (presumably Unexploded Ordnance [UXO]) or non-TOI (presumably harmless scrap) would dramatically decrease the total cost of munitions responses. It will also expedite munitions response schedules. Advanced geophysical sensor arrays will also more precisely locate target anomalies, improving geophysical survey quality in cluttered areas and reducing data management challenges related to linking geophysical anomalies with subsurface anomaly sources. Dynamic data collection with advanced sensors is typically slower and more costly than equivalent EM61 surveys.

### **2.3.2 Cued Data Collection with MetalMapper**

Collection of cued data using MM results in lower noise and higher resolution data, which typically produce more accurate inversion results and a better basis for anomaly classification. Cued data collection requires a previous dynamic survey to identify targeted anomalies, resulting in increased geophysical survey costs.

### **2.3.3 Library Matching**

LM, currently integrated within the UX-Analyze package, is conceptually easy to grasp and utilize. The tool is flexible in that it allows user inputs into the library, which allows easy adaptation to new sites and TOI types. The limitations of LM include the relatively limited

scope/utilization of existing data when compared to other data mining methods. The software is tied to a commercially available rather than publicly available software package.

### 3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration, provided in Table 1, serve as a basis for the evaluation of the performance and costs of the demonstrated technology. These objectives are for MM dynamic data collection, MM cued data collection, and MM data analysis and classification.

**Table 1. Quantitative Performance Objectives for this Demonstration**

Performance Objective	Metric	Data Required	Success Criteria
<b>Data Collection Objectives</b>			
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	90% <15 cm along-line spacing
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	≥85% coverage at 0.75 m line spacing and ≥98% coverage at 1 m line spacing (open area only) calculated using UX-Process Footprint Coverage QC Tool
Repeatability of IVS measurements	Amplitude of electromagnetic anomaly Measured target locations	Twice-daily IVS survey data	<i>Advanced Sensors Dynamic Survey:</i> Amplitudes ±10% down-track location ±10 cm
			<i>Advanced Sensors Cued:</i> Polarizabilities ±10%
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo
<b>Analysis and Classification Objectives</b>			
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Correctly classify 100% of TOI
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% of non-TOI classified in Category 3 while retaining all TOI
Specification of no-dig threshold	Percentage of TOI placed in Categories 1 or 2 and percentage of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted MM cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the sensor's detection list
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 $\sigma$ ) Z <10 cm (or 1 $\sigma$ )

### **3.1 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING**

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability to collect data with acceptable along-line measurement spacing.

#### **3.1.1 Metric**

The metrics for this objective are the percentage of data points within acceptable along-line spacing.

#### **3.1.2 Data Requirements**

A mapped data file will be used to judge the success of this objective.

#### **3.1.3 Success Criteria**

This objective is considered to be met for the MM if at least 90% of the mapped data points are spaced no more than 15 cm along the survey line.

### **3.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE**

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain valid data.

#### **3.2.1 Metric**

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC Tool.

#### **3.2.2 Data Requirements**

A mapped data file will be used to judge the success of this objective.

#### **3.2.3 Success Criteria**

This objective is considered to be met if the survey achieved at least 85% coverage at 0.75-m line spacing and 98% at 1-m line spacing (open field area only) calculated using the UX-Process Footprint Coverage QC Tool.

### **3.3 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS**

The reliability of the survey data depends on the proper functioning of the survey equipment. This objective concerns the twice-daily confirmation of sensor system performance.

#### **3.3.1 Metric**

The metrics for this objective are the amplitude and down-track position of the maxima for the MM in dynamic survey mode and the standard deviation of the polarizabilities for the advanced sensors in cued mode obtained from each of the twice-daily surveys of the instrument verification strip (IVS).

### 3.3.2 Data Requirements

The data will be used to judge this objective.

### 3.3.3 Success Criteria

The objective is considered met for the MM in dynamic survey mode if the measured amplitudes for each object are within 10% of the mean, and the down-track position of the anomaly is within 10 cm of the known location. The objective is considered met in cued mode if the standard deviation of the estimated polarizabilities is within 10% of the mean.

## 3.4 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued mode data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

### 3.4.1 Metric

The metric for this objective is the percentage of anomalies that are within the acceptable distance of the center of the instrument during data collection from the actual target location.

### 3.4.2 Data Requirements

URS provided the ESTCP Program Office with the location of the instrument center for each cued anomaly interrogated.

### 3.4.3 Success Criteria

The objective is considered to be met if the MM center is positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

## 3.5 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

Quality data should lead to a high probability of detecting TOI at the site.

### 3.5.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

### 3.5.2 Data Requirements

URS prepared an anomaly list. Institute for Defense Analyses (IDA) personnel scored the detection probability of the seed items.

### 3.5.3 Success Criteria

The objective is considered to be met if 100% of the seed items are detected within a halo of 60 cm.

### **3.6 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST**

This is one of the two primary measures of the effectiveness of the classification method. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, URS expected to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves correct classification of TOI.

#### **3.6.1 Metric**

The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI.

#### **3.6.2 Data Requirements**

URS prepared a ranked anomaly list for the targets on the sensor anomaly list. IDA personnel used scoring algorithms to assess the results.

#### **3.6.3 Success Criteria**

The objective is considered to be met if all of the TOI are correctly labeled as TOI on the ranked anomaly list.

### **3.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST**

This is the second of the two primary measures of the effectiveness of the classification method. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, URS expected to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

#### **3.7.1 Metric**

The metric for this objective is the percentage of non-TOI items that are correctly classified as non-TOI by the classification method.

#### **3.7.2 Data Requirements**

URS prepared a ranked anomaly list for the targets on the sensor anomaly list. IDA personnel used scoring algorithms to assess the results.

#### **3.7.3 Success Criteria**

The objective is considered to be met if more than 75% of the non-TOI items can be correctly labeled as non-TOI while retaining all the TOI on the dig list.

### **3.8 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD**

In a retrospective analysis, as performed in this demonstration, it is possible to determine the true capabilities of a classification process based solely on the ranked anomaly list submitted by each

demonstrator. In a real-world scenario, all targets may not be dug, so the success of the approach depends on the ability of an analyst to accurately specify their dig/no-dig threshold.

#### 3.8.1 Metric

The probability of correct classification of TOI (Pclass) and number of false alarms (Nfa) at the demonstrator-specified threshold are the metrics for this objective.

#### 3.8.2 Data Requirements

URS prepared a ranked anomaly list with a dig/no-dig threshold indicated. IDA personnel used scoring algorithms to assess the results.

#### 3.8.3 Success Criteria

The objective is considered to be met if URS sets a dig/no-dig threshold that results in more than 75% of the non-TOI items being correctly labeled as non-TOI, while correctly identifying all the TOI.

### **3.9 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED**

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be considered TOI and reduce the effectiveness of the classification process.

#### 3.9.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

#### 3.9.2 Data Requirements

URS provided a list of all parameters as part of the results submission, along with a list of those anomalies for which parameters could not be reliably estimated.

#### 3.9.3 Success Criteria

The objective is considered to be met if reliable parameters can be estimated for more than 95% of the anomalies on the sensor's anomaly list.

### **3.10 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS**

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

#### 3.10.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

### 3.10.2 Data Requirements

Each analyst in demonstration reports compared estimated parameters for the seed items to those expected.

### 3.10.3 Success Criteria

The objective is considered to be met if the estimated polarizabilities are within  $\pm 20\%$ , the estimated X, Y locations are within 15 cm ( $1 \sigma$ ), and the estimated depths (Z) are within 10 cm ( $1 \sigma$ ).

## **4.0 SITE DESCRIPTION**

### **4.1 SITE SELECTION**

This site was chosen as one in a series of sites for demonstration of the munitions classification process. Sites including this one provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions. Further information about ESTCP's classification program can be found at <http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response>.

### **4.2 SITE HISTORY**

From 1942 to 1951, the US Army used the MRS as an anti-tank rocket/grenade range. During the mid-1950s, much of the former anti-tank rocket/grenade range (approximately 38 acres) was developed as part of a larger golf course that was constructed for use by Fort Rucker personnel. The golf course has been in continuous operation since construction, with various modifications to course design as well as irrigation layout. The remainder of the MRS (approximately 14 acres) is wooded.

Most of the MRS consists of well-maintained grassy areas with few trees. The wooded areas generally lack significant undergrowth and are easily accessible. Most of the ground surface in the wooded areas is covered with leaf litter and fallen limbs/trees. Access is open to military personnel and the general public. Fort Rucker Morale, Welfare, and Recreation personnel have placed signage inside the clubhouse and on the course warning patrons of dangers of potential MEC. Although warnings are prominently displayed, this course (one of the three 9-hole courses that make up the Silver Wings Golf Course Complex) continues to be heavily used. Subsets of the MRS will be selected for the ESTCP study with focus on the golf course fairways and rough (TetraTech EC 2012).

### **4.3 SITE GEOLOGY**

Fort Rucker lies in the East Gulf Coastal Plain physiographic section, with sedimentary origins dating to the Cretaceous, Tertiary, and Quaternary ages. Fort Rucker soils overlie the Buhrstone Escarpment, a formation held up by Early Tertiary shale and sandstone. Geologic formations that outcrop on Fort Rucker are Tertiary to Holocene in age and include the Tuscaloosa Sand, Hatchetigbee and Tallahatta Formations, Lisbon Formation, Residuum, Alluvial High Terrace Deposits, and Low Terrace Deposits. These formations strike east-west, dipping to the south at a rate of 15 to 40 ft per mile (CH2M HILL 2011).

### **4.4 MUNITIONS CONTAMINATION**

Malcolm Pirnie performed a Site Inspection (SI) in support of the U.S. Army Corps of Engineers (USACE) Baltimore District, during which 2.36-in. and 3.5-in. rocket fragments and an expended practice rifle grenade were discovered. The SI consisted of a magnetometer-assisted site walk (10% of undeveloped portions of the range) and 10 surface soil samples. The site walk identified 20 subsurface anomalies, and soil sample results indicated detectable concentrations of nitrobenzene, although not in sufficient quantities to exceed regulatory screening values (Malcolm Pirnie 2005).

A RCRA Facility Inspection (RFI) was performed in January and February 2012 by CH2M HILL on behalf of the USACE Mobile District. The RFI focused on DGM using a man-portable EM61-MK2 time domain induction detector with 30-m spacing. A total of 1,059 anomalies were detected; of these, approximately 229 anomalies were intrusively investigated. This effort resulted in the recovery and disposition of 22 MEC, including M6 series 2.36-in. rockets, M9A1 rifle grenades, and one MK II hand grenade (CH2M HILL 2011).

## 5.0 TEST DESIGN

URS had two roles in this project:

- MM data collection and processing and
- MM data analysis and anomaly classification.

URS collected both dynamic survey mode and cued mode data using the MM advanced geophysical sensor array. A URS geophysicist classified anomalies using the cued mode MM data. This section discusses the activities that were executed by URS in support of this project.

### 5.1 CONCEPTUAL EXPERIMENTAL DESIGN

- **Demonstration/Work Plan Development:** URS prepared a demonstration plan describing MM data collection and data processing activities for this project site.
- **MM Data Collection:** The MM system was used to collect dynamic data over Fairway #6 (approximately 4.4 acres) and cued data on 407 anomalies in the Demonstration Area, 377 anomalies in Fairway #1, 430 anomalies in Fairway #6, and 137 anomalies in Fairway #9.
- **MM Data Processing:** URS used the Geosoft UX-Analyze software package to process and invert the MM data.
- **MM Data Analysis and Classification:** URS used the inversion results for 402 targets to classify them using LM within UX-Analyze.

### 5.2 CALIBRATION ACTIVITIES – INSTRUMENT VERIFICATION STRIP

URS used an IVS installed by TetraTech to verify the proper operation and functioning of the geophysical equipment used and to measure site noise readings of the MM before and after each day of field data collection. The IVS was installed and operated consistently with the specifications and descriptions contained in *Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove Outs for Munitions Response* (ESTCP 2009). The IVS also served to verify that geo-location systems provided accurate sensor location data. Industry standard objects and inert munitions were used as reference seed items. The IVS contained five seed items of the sizes, at the depths, and in the orientations listed in Table 2. A sixth location with no seed item was also included in the IVS. Seed items were placed horizontally across-track.

**Table 2. Silver Wings Golf Course Complex Fort Rucker Instrument Verification Strip**

Item ID	Description	Easting (ft)	Northing (ft)	Depth (m)	Inclination	Orientation
T-001	Hand Grenade	700288.492	310655.361	0.2	Horizontal	Across Track
T-002	Blank	700288.638	310662.229	N/A	N/A	N/A
T-003	Rifle Grenade	700288.786	310669.219	0.2	Horizontal	Across Track
T-004	2.36 inch Rocket	700288.938	310676.208	0.3	Horizontal	Across Track
T-005	Medium ISO	700289.011	310683.27	0.45	Horizontal	Across Track
T-006	Small ISO	700289.136	310689.911	0.15	Horizontal	Across Track

### 5.3 DATA COLLECTION – METALMAPPER ADVANCED SENSOR IN DYNAMIC SURVEY MODE

#### 5.3.1 Sample Density

The dynamic survey mode consisted of complete coverage in Fairway #6. Figure 1 shows dynamic data collection, with the MM using an onscreen real-time display to maintain transect spacing. Data were collected along parallel transects with 0.75 m nominal transect spacing; however, it was necessary for some transects to deviate from a straight line path due to obstructions. Sample rate and survey pace were slow enough to ensure down-line spacing of less than 15 cm. Survey position was recorded and logged using an RTK GPS.



**Figure 1. MM Dynamic Data Collection**

#### 5.3.2 Quality Checks

**Equipment Warm-Up:** Field personnel followed the manufacturer’s instructions for a warm-up period prior to data acquisition.

**IVS:** Survey personnel collected data over the IVS in each direction in the morning and after the data collection day.

**Battery Strength Test:** At the beginning of the day and periodically throughout use, the survey personnel checked the battery power remaining and replaced batteries as necessary.

**Verify Configuration and Initialization Files:** Prior to any data acquisition, the field team reviewed the configuration and initialization files for the acquisition software. The field team confirmed they had the latest acquisition software, appropriate configuration, and initialization files.

### 5.3.3 Data Summary

Discrete data files were created for each of the following events:

- Each time the IVS was performed;
- For each planned transect through the area;
- Each time an issue with the system that could have a significant impact on data quality was identified and corrected (e.g., loose wheel, loose cable, metal caught on system).

Files were named on the field computer using the associated planned transect as an identifier. For example, “DynamicTestF000049” would be the data associated with the planned transect number 49.

## 5.4 DATA COLLECTION – METALMAPPER ADVANCED SENSOR IN CUED MODE

### 5.4.1 Sample Density

The cued mode consisted of surveying static data over a list of anomalies identified from the previously collected TetraTech EM61 survey. Cued data were collected over each identified anomaly, with measurements repeated as necessary due to offsets of the sensor relative to the anomaly source or other data quality issues. Cued data were collected directly over the anomaly location as indicated either by the sensor positioning system or a reacquired flag location.

When operating the MM, the data acquisition system software was used to help select a new location based on the preliminary analysis where the software identified the anomaly source location. In these situations, data were collected directly over the anomaly source location if it was within 50 cm of the original selected anomaly location. If it was farther away than 50 cm from the original location, and not within 50 cm of another anomaly location, the original location was surveyed. The data file associated with the new location was associated with the original anomaly identification (ID) and was recorded in the field log as an added point offset from the original location. Figure 2 shows cued data collection with the MM.



**Figure 2. MM Cued Data Collection**

#### 5.4.2 Quality Checks

**Equipment Warm-Up:** Field personnel followed the manufacturer’s instructions for a warm-up period prior to data acquisition.

**IVS:** Cued responses were collected over each item in the IVS at the beginning and end of each day to demonstrate response repeatability over known sources. These responses were also used as training data for classifier routines.

**Battery Strength Test:** At the beginning of the day and periodically throughout use, data collection teams checked the battery power remaining and replaced batteries as necessary.

**Background Response Measurement:** Cued responses were collected at regular intervals at locations where no metallic source was known to be present based on previous DGM data. These locations represent the typical geologic response of the cued mode area. The interval between background response measurements was generally 1 hour but could have been less due to restarting equipment or changing field conditions (i.e., rain).

**Verify Configuration and Initialization Files:** Prior to any data acquisition, the field team reviewed the configuration and initialization files for the acquisition software. The field teams confirmed they had the latest acquisition software, appropriate configuration, and initialization files for the system setup.

### 5.4.3 Data Summary

Raw MM data were collected and stored as .tem files. The MM acquisition software uses a convention for assigning a unique name to each data file without the need to manually enter the name. The operator supplies a prefix for the root name of the file (e.g., “T”). The acquisition software then automatically appends a 5-character numerical index to the filename prefix to form a unique root name for the data file (e.g., T00001). The index is automatically incremented after the file has been successfully written. Although the target ID is not used as the file name in the .tem file, the target ID is stored in the file according to name of the target highlighted on the MM screen during collection.

Preprocessing of the .tem files was accomplished using TEM2CSV, a program specifically developed for this purpose. TEM2CSV subtracted the site background from the data point using a background file specified by the user, converted the points from the geographic coordinate system used for collection to the Universal Transverse Mercator (UTM) Zone 16N coordinate system used for processing, and exported the resulting data to a .csv file that could be imported into the UX-Analyze package in Geosoft’s Oasis Montaj software. The exported .csv file name contained both the collection ID and the target ID (e.g., FR\_T00001\_10004). Preprocessing was typically completed in batches representing approximately 1 hour of data collection, with the day split to account for differing background data. Background files were collected approximately every hour during data collection in a predetermined geophysically quiet location within the survey area. Unless there appeared to be a problem with a specific file, data were typically corrected using a background file collected at a similar time and location.

## 6.0 DATA ANALYSIS AND PRODUCTS

### 6.1 METALMAPPER DATA PROCESSING AND INTERPRETATION

URS used the Geosoft UX-Analyze software package to process and invert the MM data. Prior to classification, inversion results were reviewed to determine whether data were of sufficient quality to classify the target anomaly source. Both single- and multi-source inversions were reviewed for data quality to determine whether the inversion fits cohesions were more than 0.75 and the inverted anomaly source locations were within 0.6 m of the MM location. Typically inverted results that did not meet these criteria would be selected for recollection. However, due to schedule constraints and equipment issues no points were recollected.

#### 6.1.1 Evaluation of Inversion Results

The fit cohesion coherence parameter output from the UX-Analyze inversion was used to initially determine whether the inversion results were sufficient to perform classification. Fit cohesion results below 0.65 were determined to be of insufficient quality for further analysis. Figure 3 shows a plot of the MM cued mode data for Fit\_Coh sorted from lowest to highest cohesion. Based on these results, 2 targets out of 402 were flagged as cannot analyze and moved to the dig list.

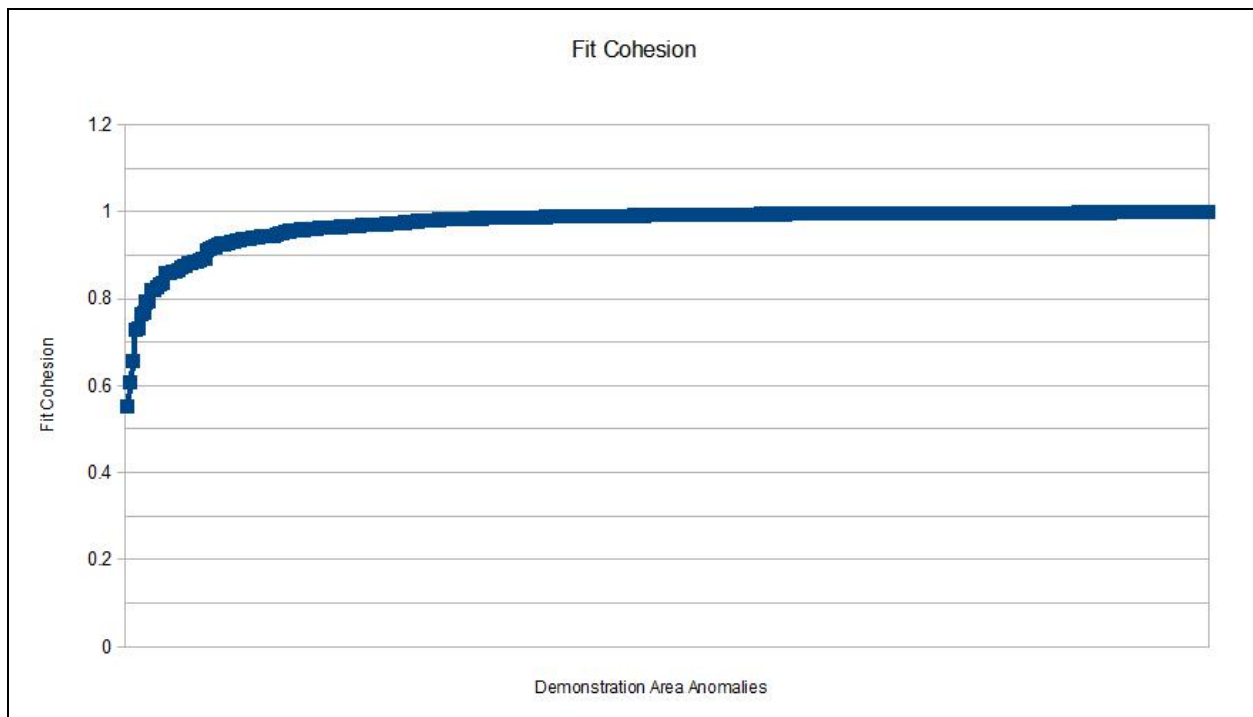


Figure 3. Plot Showing Fit\_Coh Values

### 6.2 METALMAPPER CUED MODE DATA ANALYSIS AND CLASSIFICATION METHODS

Inversion results were classified using LM in an iterative approach where targeted anomalies were group together based on "best fit" and evaluated based on any known sources for other anomalies within the group. Classification was conducted in four steps.

- Step 1: Cued inversion results were matched to their best fit TOI using the LM routine and results that shared a best fit were grouped together in a cluster.
- Step 2: One or more examples from each cluster were chosen as training data. Training data were typically selected from among the best matches. Training data results were incorporated into the library of TOI responses, and the LM routine was repeated.
- Step 3: Anomalies that showed good fit to known TOI were selected for intrusive investigation or as further training data. Clusters with known TOI had additional training data selected to determine a threshold below which lower quality matches no longer represented TOI.
- Step 4: Step 3 was repeated until all groups were identified as either non-TOI or potential TOI, and a threshold between non-TOI and TOI within the potential TOI groups could be determined.

The UX-Analyze software contains inversion codes that allow for both a single source solution and an inversion determined number of sources (multi-source). The existing library consists of single-source solutions. URS utilized single-source inversion results for the following analyses, except when multi-source inversion results fit known TOI. These were then added to either the training data or the final target list.

#### 6.2.1 Library Matching

The UX-Analyze LM algorithm was run on the inverted polarizabilities within the Demonstration Area at Fort Rucker. The algorithm compared the inverted polarizability with a library of known target polarizability signatures, and generated a fit quality for each item within the library. Usually the best, or primary, fit was used to determine whether the item represented a TOI.

The initial library was composed of default responses provided with the UX-Analyze software package, along with IVS data collected at Fort Rucker.

##### 6.2.1.1 Clustering of Library Matching Results

Initial LM results were grouped into clusters determined by having a common primary fit within the library. Based on the expectation that not all the TOI within the existing library would be relevant to the TOI present at Fort Rucker, clusters were evaluated to determine the likelihood that the best fits within the cluster represented TOI.

One or more inverted responses from each cluster were selected as training data. If the training data results showed that the cluster contained TOI, further training data were selected in an attempt to refine the boundary between higher quality fits, which were assumed to be most likely TOI, and lower quality fits within the cluster than might not represent TOI. Clusters where the best possible fit did not indicate TOI were considered to contain non-TOI and were not investigated further, unless responses within the cluster showed good matches to new TOI added to the library from the training data.

##### 6.2.1.2 Training Data Selection

Table 3 shows an example spreadsheet of how the clustering and LM results were combined for visual review. Each response associated with known TOI was colored blue and each response

associated with non-TOI was colored gray. These charts were used to identify clusters that were highly likely to contain TOI and those highly unlikely to contain TOI.

**Table 3. Example of Training Data Selection**

ID	Investigation Result	Fit Cohesion	Library Match Fit	Library Match Best Fit
10515	2.36 rkt frag	0.9972	<b>0.91431</b>	2.36-in
10037	Seed # ?? 2.36 Rkt (Shared w/10035)	0.9871	<b>0.91236</b>	2.36-in
10401	Seed #003	0.9964	<b>0.90181</b>	2.36-in
10513	Seed #025 2.36 Rkt	0.9923	<b>0.90126</b>	2.36-in
10801	2.36 Rkt (Shared w/10793)	0.9921	<b>0.89845</b>	2.36-in
10035	Seed # ?? 2.36 Rkt (Shared w/10035)	0.995	<b>0.88894</b>	2.36-in
10506	Seed #025 2.36 Rkt (Shared w/10513)	0.9924	<b>0.88792</b>	2.36-in
10808	seed #022	0.9989	<b>0.85753</b>	2.36-in
10793	2.36 Rkt	0.9956	<b>0.8522</b>	2.36-in
10608	2.36 Rkt Mtr & 4 pcs frag	0.9905	<b>0.79854</b>	2.36-in
10581	2.36 Rkt Mtr & 2 pcs frag	0.995	<b>0.78247</b>	2.36-in
10663	2.36 Rkt Mtr	0.9937	<b>0.7718</b>	2.36-in
10715	2.36 rkt mtr	0.9902	<b>0.75089</b>	2.36-in
10707	2.36 rkt mtr (Shared w/10704)	0.9946	<b>0.74523</b>	2.36-in
10704	2.36 rkt mtr (Shared w/10704)	0.9943	<b>0.72931</b>	2.36-in
10032	2.36 Rkt Mtr (Shared w/10031)	0.9913	<b>0.72412</b>	2.36-in
10585	2.36 rkt mtr & 3 pcs frag (shared w/10585)	0.9804	<b>0.61878</b>	2.36-in
10166	2.36 Rkt Mtr & 2 pcs frag	0.9951	<b>0.84678</b>	2.36" rocket
10058	Target Debris	0.9676	<b>0.65689</b>	2.36" rocket
10517	2.36 Rkt	0.9972	<b>0.86484</b>	2.36" rocket (oblong warhead)
10761	2.36 Rkt Frag	0.9896	<b>0.81672</b>	2.36" rocket (oblong warhead)
10781	2.36 Rkt Mtr	0.9731	<b>0.73387</b>	2.36" rocket (oblong warhead)
10691	2.36 Rkt Frag	0.991	<b>0.71404</b>	2.36" rocket (oblong warhead)
10538	2.36 Rkt Warhead	0.9977	<b>0.89029</b>	2.36" rocket warhead
10030	Target Debris & 4 pcs frag	0.9708	<b>0.73399</b>	2.36" rocket warhead
10686	2.36 Rkt Frag (Shared w/10691)	0.9265	<b>0.72782</b>	2.36" rocket warhead
10818	2.36 Rkt Mtr	0.9986	<b>0.76125</b>	2.36"rocket
10081	2.36 Rkt Mtr & 3 pcs frag	0.9975	<b>0.71507</b>	2.36"rocket
10688	2.36 rkt mtr (Shared w/10687)	0.9972	<b>0.63928</b>	2.36"rocket
10054		0.99	<b>0.52147</b>	2.36"rocket
10229	Seed #016 2.36 Rkt	0.9956	<b>0.87736</b>	2.36in Rocket FR_IVS
10749	Seed #w030 (Usace) or #019 2.36 Rkt	0.9981	<b>0.84904</b>	2.36in Rocket FR_IVS
10607	2ea 2.36 rkt mtr & 3 pcs frag	0.8592	<b>0.84406</b>	2.36in Rocket FR_IVS
10416	2.36 rkt (Shared w/10416)	0.989	<b>0.80002</b>	2.36in Rocket FR_IVS
10417	2.36 rkt (Shared w/10416)	0.9873	<b>0.79757</b>	2.36in Rocket FR_IVS
10013	24" Pipe	0.9768	<b>0.64347</b>	2.36in Rocket FR_IVS
10800	3.5 Rkt frag	0.998	<b>0.86685</b>	2.5 inch ballistic windshield
10562		0.9526	<b>0.74742</b>	2.5 inch ballistic windshield
10629	2.36 Rkt Frag	0.9761	<b>0.7503</b>	20mm projectile
10633		0.9924	<b>0.57874</b>	20mm projectile
10787		0.9867	<b>0.50987</b>	20mm projectile
10639		0.987	<b>0.38264</b>	20mm projectile
10844		0.9991	<b>0.36422</b>	20mm projectile
10810		0.938	<b>0.32262</b>	20mm projectile
10038		0.9846	<b>0.25479</b>	20mm projectile
10768		0.9895	<b>0.24446</b>	20mm projectile
10692		0.9877	<b>0.14471</b>	20mm projectile

### 6.2.1.3 Final Ranked Anomaly List

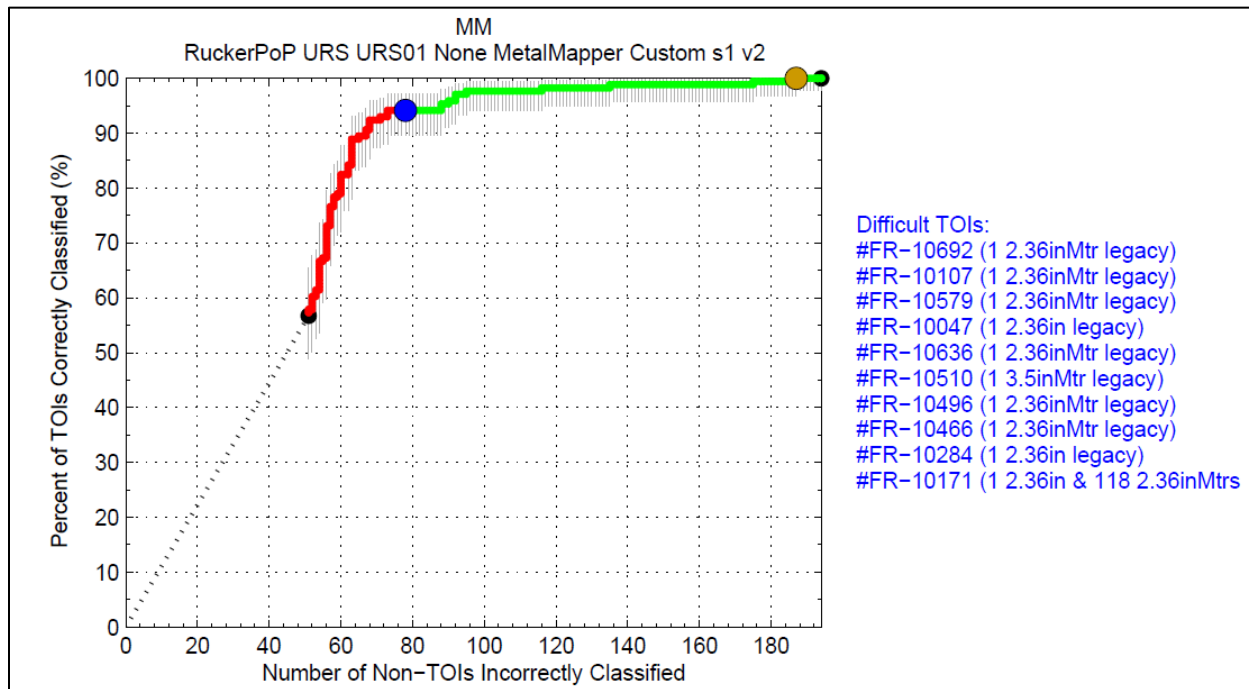
After incorporating the training data into the LM list, a ranked anomaly list was submitted based on the results.

### 6.3 DATA PRODUCTS

Table 4 provides the general prioritized target list statistics, and Figure 4 provides the plotted results.

**Table 4. General Prioritized Target List Statistics**

List Name	TOI Identified		Training Targets		Cannot Analyze		List Length		Total Targets
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	
Fort Rucker LM	201	95%	163	40.10%	2	0.50%	296	74%	402



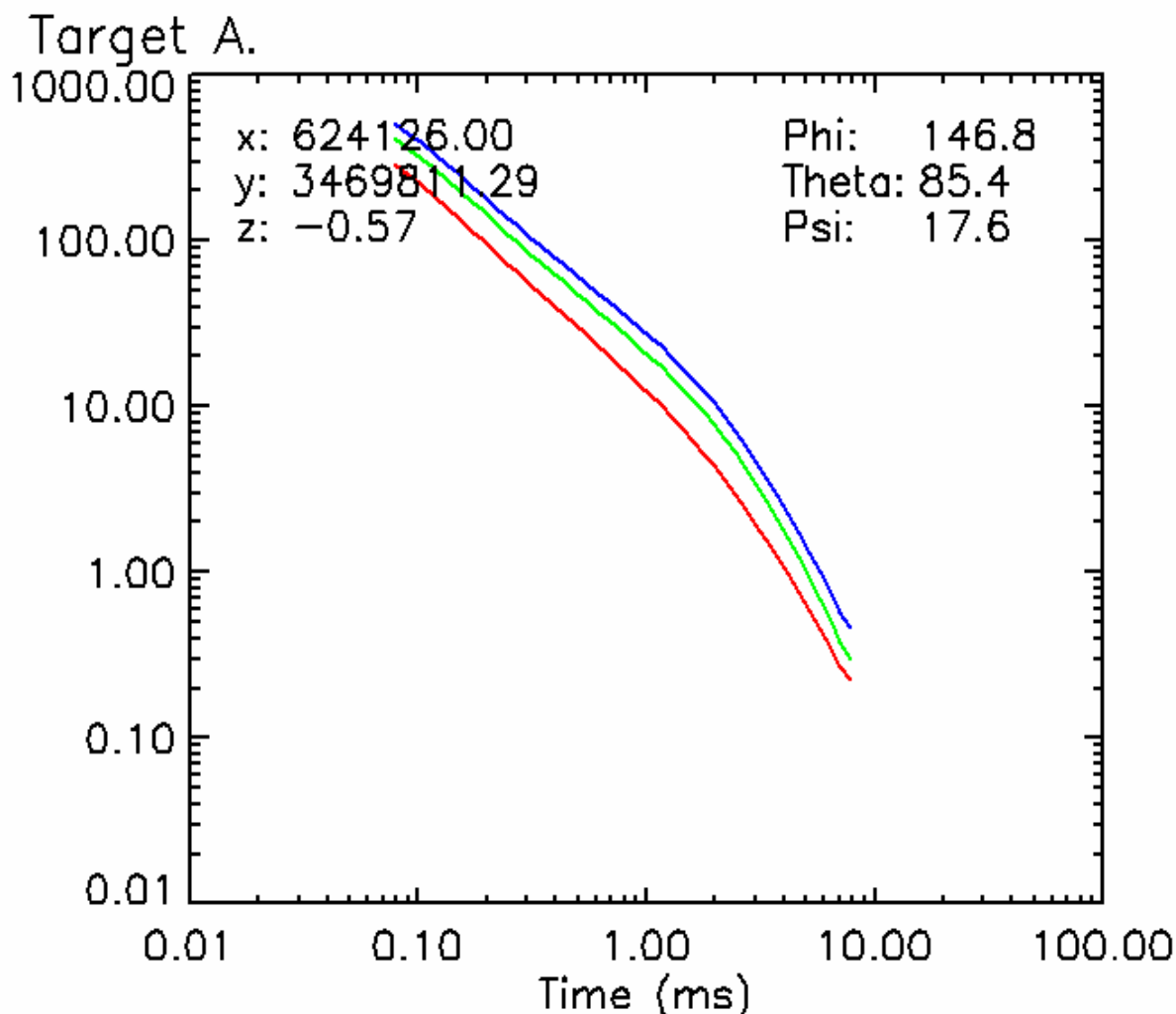
**Figure 4. Classification Results Plot**

### 6.4 FAILURE ANALYSIS

All the QC seeds were detected in the final target list. 10 TOI were not detected in the final target list, shown in blue on Figure 4.

Two of these seeds, FR-10466 and FR-10510, were identified on a revised target list submitted August 21, 2013, that was not scored.

Of the remaining 8 TOI, one response, FR-10171, should have been selected based on the selection criteria, but was ruled out by the analyst based on response characteristics atypical of a single TOI. The response best matched a 155mm projectile, with a fit of 70%. However, no 155mm projectiles were expected on the site and the response curve shown in Figure 5 shows the single inversion fit for an item that appears to be plate-like. Based on this reasoning, it was removed from the training data request list and not selected for intrusive investigation. In this case, the response represented a burial pit containing multiple TOI.



**Figure 5. Polarizability Inversion Results for FR-10171**

Two targeted anomalies, FR-10284 and FR-10692, were the only cued responses within their respective clusters that yielded TOI. FR-10692 did not match well with any responses in the TOI library, TOI from the training data, or TOI identified in the initial intrusive investigation results. The best fit was 14% to a 20mm projectile, but the actual intrusive investigation yielded a 2.36-in. rocket motor and two pieces of munitions debris. FR-10284 matched well to a 57mm projectile, with a fit of 87%. The 57mm projectile was selected as training data and was found to be associated with target debris. Using this result, and expectations that no 57mm projectiles were present on-site, this cluster of four anomalies was deemed to not be associated with TOI. After initial intrusive investigation results were incorporated into the TOI library, further LM indicated a best fit of 62% to FR-10553, a 3.5-in. rocket motor. This fit was not of high enough quality to move FR-10284 into the intrusive investigation list submitted on August 21. Intrusive investigation revealed a 2.36-in. rocket warhead and 10 pieces of munitions debris.

Cued responses at FR-10047 and FR-10579 best fit the 'Fuze Part' included in the UX-Analyze library, along with 36 other responses; none of which yielded a TOI. The fit qualities to the 'Fuze Part' response were 54% and 55%, respectively, and represent poor fits as TOI are typically found at fits more than 75% to other TOI. After initial intrusive investigation results

were incorporated into the TOI library, further LM indicated a best fit of 54% and 32%, respectively, to FR-10597 where a 2.36-in. rocket and two pieces of frag were recovered. These fits were deemed not sufficient to move FR-10047 and FR-10579 into the intrusive investigation list submitted on August 21. Intrusive investigation revealed a 2.36-in. rocket warhead and five pieces of munitions debris at FR-10047 and a 2.36-in. rocket motor at FR-10579.

Cued responses at FR-10107, FR-10496, and FR-10636 all fell within clusters that contained TOI. However, these responses all had low fit qualities (55%) not typically associated with TOI and did not match well with any of the TOI identified in the training data and initial intrusive investigations.

The TOI missed on the August 21 list did not match well with any of the other TOI recovered at the site through the training data; nor did they match well with any TOI recovered during the initial round of intrusive investigation comprising roughly one-half of the investigated anomalies. This suggests that any advanced analysis/data mining techniques will have difficulty with the inverted polarizabilities comprising this dataset, as they depend on associating similar responses to identify TOI.

The clustering approach used in this application of LM appears to have been unsuccessful, with three TOI appearing in two clusters that were deemed to not contain TOI based on training data and initial intrusive investigations. Future improvements might include a more comprehensive TOI library, and clustering based on a more broad view of the response characteristics rather than just LM fits.

## 7.0 PERFORMANCE ASSESSMENT

The performance objectives for this demonstration are summarized in Table 1 and are repeated here as Table 5. The results for each criterion are discussed in the following sections.

**Table 5. Quantitative Performance Objectives and Results**

Performance Objective	Metric	Data Required	Success Criteria
<b>Data Collection Objectives</b>			
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	90% <15 cm along-line spacing
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	≥85% coverage at 0.75 m line spacing and ≥98% coverage at 1 m line spacing (open area only) calculated using UX-Process Footprint Coverage QC Tool
Repeatability of IVS measurements	Amplitude of electromagnetic anomaly Measured target locations	Twice-daily IVS survey data	<i>Advanced Sensors Dynamic Survey:</i> Amplitudes ±10% down-track location ±10 cm
			<i>Advanced Sensors Cued:</i> Polarizabilities ±10%
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo
<b>Analysis and Classification Objectives</b>			
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Correctly classify 100% of TOI
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% of non-TOI classified in Category 3 while retaining all TOI
Specification of no-dig threshold	Percentage of TOI placed in Categories 1 or 2 and percentage of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted MM cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the sensor's detection list
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 $\sigma$ ) Z <10 cm (or 1 $\sigma$ )

## 7.1 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

URS utilized tools within Geosoft's Oasis Montaj to calculate sample separations. Currently available processing tools for MM dynamic data do not interpolate locations between RTK GPS readings. Within the Oasis Montaj database file, URS created a distance channel that contains a sum of the distance up to that record. An initial sample separation distance was calculated using the user-defined convolution filter with a filter of (-1, 1, 0) applied to the distance channel to generate a separation distance. Distance channel values associated with separation distances of less than 0.04 m were then masked and the resulting gaps were filled using linear interpolation. A final sample separation distance was calculated. A histogram of sample separation distances was generated, showing that 99.96% of samples were less than the 15 cm tolerance, relative to an allowed 90% of samples less than 15 cm.

## 7.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

URS utilized Geosoft's Oasis Montaj UX-Process Footprint Coverage QC Tool. Footprint coverage metrics were calculated with masks applied to exclude areas around trees near the northern edge of Fairway #6. Footprint coverage over the site was 86.8% at a 0.75-m line width, and 98.9% at a 1-m line width and is shown in Figure 6.

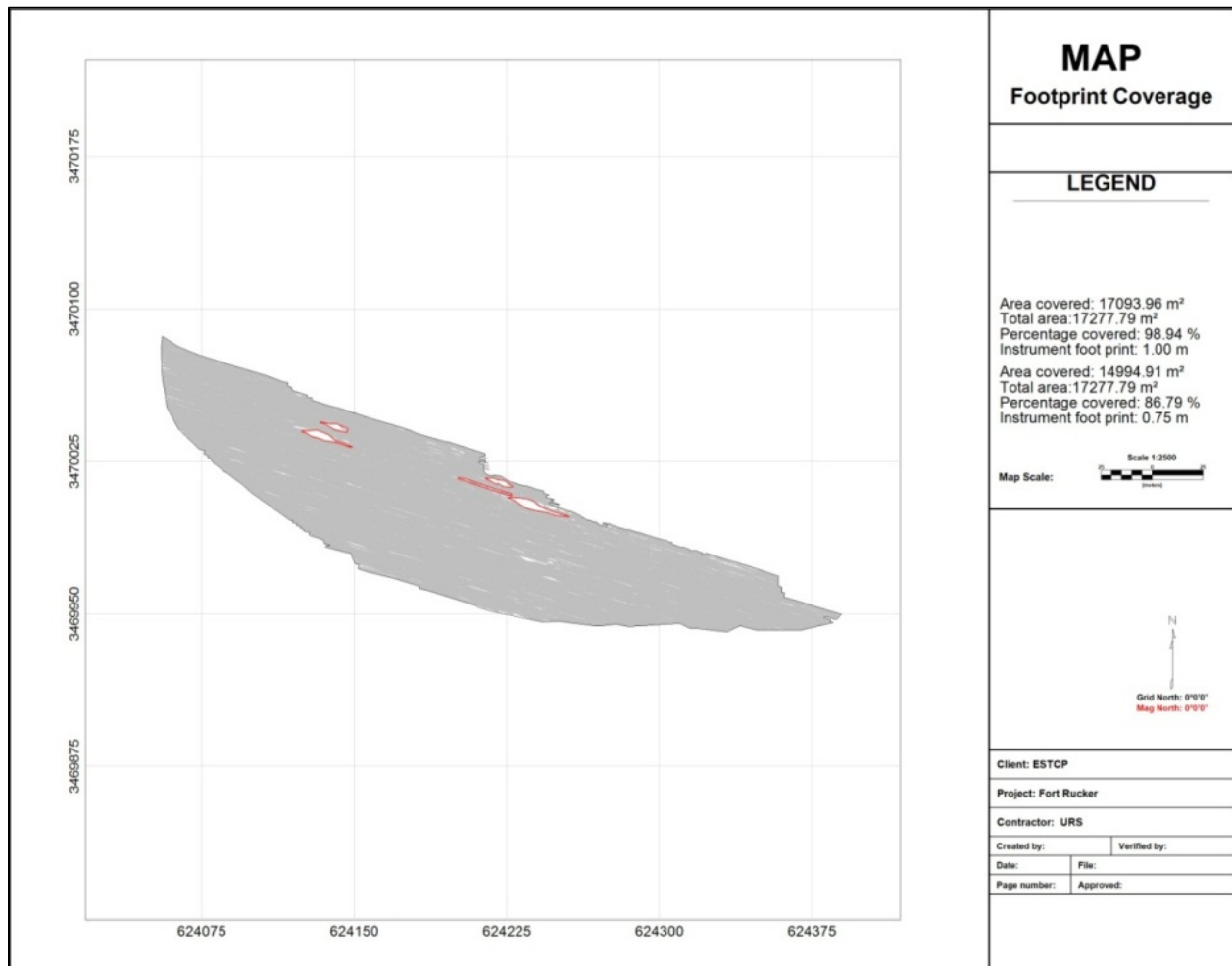


Figure 6. UX-Process Footprint Coverage

### **7.3 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS**

Advanced sensor dynamic survey data analysis tools were not available, so peak amplitude response of the center, horizontal receiver, over a summed window from 8 to 35 time gates after the pulse was used to evaluate repeatability within the IVS. Responses were leveled to a common background using a simple demedian filter to subtract the median value from the responses.

The center receiver responses are shown in Table 6. Responses to the center receiver in the vertical component (horizontal receiver loop) proved to be highly variable and unusable for purposes of evaluating repeatability.

Down-track peak locations showed considerable variability, likely associated with latency between the instrument response and the RTK GPS location. No latency correction was applied to the dynamic IVS data. Down-track peak location offsets are shown in Table 7.

Response amplitude for the MM cued data was measured by calculating the zero moment polarizability ( $P_{0x}$ ) for the primary polarizability of each response within the IVS. The zero moment is effectively an integrated value representing the area under the polarizability curve. Results for all items were within  $\pm 10\%$  of the average primary polarizability, with the exception of one inverted response over Seed T-006. This is the smallest seed item, which should show the largest percent variation in the presence of constant background noise. All the IVS zero moment polarizabilities are shown in Table 8.

### **7.4 OBJECTIVE: CUED INTERROGATION OF ANOMALIES**

The actual location of the anomaly sources was not recorded during intrusive investigation; therefore, the distance between the anomaly source and the center of the instrument cannot be evaluated.

### **7.5 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST**

The means for identifying target anomalies for MM dynamic data were not available; therefore, this check was not performed.

### **7.6 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST**

Of the 201 TOI, 95% were correctly labeled as TOI on the ranked anomaly list.

### **7.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST**

A total of 62% of the non-TOI were correctly classified by the LM-based approach.

### **7.8 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD**

The final threshold established by URS did not successfully identify 100% of the TOI and did not correctly classify 75% of the non-TOI. The last TOI fell near the very end of the ranked list of anomalies, so further refinement of the threshold would not have resulted in either objective being achieved.

**Table 6. IVS Repeatability**

Seed T-001 Rz3Tz	Percent of Average Response	Seed T-003 Rz3Tz	Percent of Average Response	Seed T-004 Rz3Tz	Percent of Average Response	Seed T-005 Rz3Tz	Percent of Average Response	Seed T-006 Rz3Tz	Percent of Average Response
194.79	31%	617.66	55%	621.64	63%	187.89	46%	215.33	46%
742.13	117%	1267.39	114%	1098.22	111%	325.51	80%	347.27	74%
638.13	101%	900.02	81%	905.59	92%	247.36	61%	148.48	32%
463.1	73%	684.69	61%	701.29	71%	240.61	59%	278.15	59%
45.34	7%	401.36	36%	436.52	44%	82.67	20%	66.06	14%
306.33	48%	1029.53	92%	981.58	99%	265.56	65%	328.14	70%
686.28	108%	1414.59	127%	1077.59	109%	502.16	123%	646.6	138%
771.89	122%	1070.34	96%	946.66	96%	358.32	88%	441.39	94%
736.6	116%	1345.52	121%	1080.5	109%	619.47	152%	743.89	159%
861.57	136%	1403.57	126%	1144.27	116%	617.52	152%	717.02	153%
837.45	132%	1418.97	127%	1182.95	120%	556.49	137%	688.23	147%
862.53	136%	1388.29	124%	1090.87	111%	584.97	144%	589.55	126%
586.95	93%	1001.26	90%	1062.67	108%	395.27	97%	405.53	87%
810.42	128%	1162.55	104%	1077.72	109%	519.94	128%	635.37	136%
797.28	126%	1525.24	137%	1232.87	125%	495.99	122%	600.54	128%
811.77	128%	1226.95	110%	1152.94	117%	508.22	125%	641.65	137%
<b>634.535</b>	Average	<b>1116.12063</b>	Average	<b>987.1175</b>	Average	<b>406.746875</b>	Average	<b>468.325</b>	Average

**Table 7. IVS Zero Moment Polarizabilities**

Seed T-001 P0x	Percent of Average Response	Seed T-003 P0x	Percent of Average Response	Seed T-004 P0x	Percent of Average Response	Seed T-005 P0x	Percent of Average Response	Seed T-006 P0x	Percent of Average Response
254.49	96%	1338.45	97%	7777.79	99%	4439.67	95%	518.49	101%
264.26	100%	1347.65	98%	7826.18	100%	4646.99	100%	520.96	101%
266.45	101%	1409.83	103%	7907.65	101%	4745.29	102%	518.42	101%
255.81	97%	1343.25	98%	7755.66	99%	4425.48	95%	508.26	99%
265.18	100%	1382.33	101%	7460.30	95%	4646.99	100%	544.68	106%
267.44	101%	1384.28	101%	7939.38	101%	4947.58	106%	557.70	108%
258.43	98%	1385.14	101%	8139.10	104%	5229.89	112%	564.36	110%
268.54	102%	1378.50	100%	7814.52	100%	4687.53	101%	523.77	102%
281.55	106%	1367.40	99%	7810.22	100%	4466.58	96%	387.25	<b>75%</b>
262.77	99%	1406.42	102%	7835.18	100%	4389.32	94%	499.62	97%
<b>264.49</b>	Average	<b>1374.33</b>	Average	<b>7826.60</b>	Average	<b>4662.53</b>	Average	<b>514.35</b>	Average

**Table 8. IVS Down-Track Peak Location Offsets**

Down Track Peak Location Offset				
T-001	T-003	T-004	T-005	T-006
-0.23	-0.15	-0.15	-0.15	-0.15
0.20	0.20	0.20	0.20	0.20
-0.21	-0.19	-0.19	-0.19	-0.19
0.23	-0.04	-0.04	-0.04	-0.04
-0.20	-0.34	-0.34	-0.34	-0.34
0.43	0.14	0.14	0.14	0.14
-0.15	-0.46	-0.46	-0.46	-0.46
0.18	0.56	0.56	0.56	0.56
-0.27	-0.33	-0.33	-0.33	-0.33
0.25	0.07	0.07	0.07	0.07
-0.37	-0.49	-0.49	-0.49	-0.49
0.25	0.25	0.25	0.25	0.25
0.45	0.14	0.14	0.14	0.14
-0.43	-0.46	-0.46	-0.46	-0.46
0.21	0.20	0.20	0.20	0.20
-0.35	-0.21	-0.21	-0.21	-0.21

## 7.9 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

URS was unable to recollect targeted anomalies where MM data could not be analyzed due to schedule constraints. However, more than 99% of targeted anomalies could be effectively analyzed using the polarizability curves generated by the UX-Analyze single- and multi-source inversions.

## 7.10 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

Since the recovered X, Y locations and the recovered depths are not available, only the estimated polarizabilities were evaluated. Response amplitude for the MM cued data was measured by calculating the zero moment polarizability ( $P_{0x}$ ) for the primary polarizability of each response within the IVS. The zero moment is effectively an integrated value representing the area under the polarizability curve. As displayed in Table 9, there is considerable variability in the inverted polarizabilities, well beyond the  $\pm 20$  polarizability objective. This higher than targeted variation in polarizabilities may result from difficulties in separating background response from measured signal, possible variations between seed items, effects stemming from the orientation and location of the seed relative to the sensor, and the variability inherent in the instrument and the inversion software.

Locations and depths for recovered items were not captured during intrusive investigation, so the location metrics X, Y <15 cm (or  $1\sigma$ ) and depth metric Z <10 cm (or  $1\sigma$ ) were not evaluated.

**Table 9. Polarizability Variation**

<b>ID</b>	<b>P0x</b>	<b>Seed Type</b>	<b>Expected P0x (from IVS or average seed)</b>	<b>Variation from Expected P0x</b>	<b>Intrusive Result</b>
FR-10035	4996.17	2.36 inch rocket	4509.19	111%	Seed # ?? 2.36 Rkt
FR-10037	3919.57	2.36 inch rocket	4509.19	87%	Seed # ?? 2.36 Rkt (Shared w/10035)
FR-10229	4766.95	2.36 inch rocket	4509.19	106%	Seed #016 2.36 Rkt
FR-10799	1045.44	2.36 inch rocket	4509.19	23%	Seed #021 2.36 Rkt
FR-10506	6207.76	2.36 inch rocket	4509.19	138%	Seed #025 2.36 Rkt (Shared w/10513)
FR-10513	6188.63	2.36 inch rocket	4509.19	137%	Seed #025 2.36 Rkt (Shared w/10513)
FR-10749	4439.79	2.36 inch rocket	4509.19	98%	Seed #w030 (Usace) or #019 2.36 Rkt
FR-10090	6745.34	2.36 inch rocket motor			Seed #009 2.36 Rkt Mtr
FR-10160	328.45	Rifle Grenade	614.80	53%	Seed #088 Rifle Grenade
FR-10384	278.37	Rifle Grenade	614.80	45%	Seed #002 Rifle Grenade
FR-10014	987.03	Rifle Grenade	614.80	161%	Seed #011 Rifle Grenade
FR-10616	865.36	Rifle Grenade	614.80	141%	Seed #018 Rifle Grenade
FR-10177	328.22	Hand Grenade	370.92	88%	Seed #007 Mk 2 Hand Grenade Practice
FR-10028	417.22	Hand Grenade	370.92	112%	Seed #010 Mk 2 Hand Grenade Practice
FR-10548	423.46	Hand Grenade	370.92	114%	Seed #017 Mk 2 Hand Grenade
FR-10771	412.16	Hand Grenade	370.92	111%	Seed #020 or 030 Mk Hand Grenade. Traing
FR-10797	273.52	Hand Grenade	370.92	74%	Seed #023 mk2 hand grenade
FR-10798	551.58	Pipe Nipple (ISO)	462.37	119%	Seed #24 Pipe Nipple
FR-10401	5812.21	Unknown	NA	NA	Seed #003
FR-10732	440.76	Unknown	NA	NA	Seed #024
FR-10808	4503.66	Unknown	NA	NA	seed #022

## 8.0 COST ASSESSMENT

The cost elements traced for this demonstration are detailed in Table 10.

**Table 10. Project Costs**

Cost Element	Data Tracked During Demonstration	Estimated Costs
<b>Project Planning</b>	Develop project-specific documents: <ul style="list-style-type: none"> <li>• Project Demonstration Plan</li> <li>• Health &amp; Safety Plan</li> <li>• Classification Decision Memo</li> </ul>	\$7,700
<b>MM Data Collection</b>	3 people (field team) data collection and processing <ul style="list-style-type: none"> <li>• Dynamic data collection on 4.4 acres in Fairway #6</li> <li>• Cued data collection on: <ul style="list-style-type: none"> <li>- 407 anomalies in the Demonstration Area</li> <li>- 377 anomalies in Fairway #1</li> <li>- 430 anomalies in Fairway #6</li> <li>- 137 anomalies in Fairway #9</li> </ul> </li> </ul> Project Geophysicist Equipment rental and repair Supplies Travel	\$120,197 (total cost includes 17.5 days of instrument downtime)  \$50,682 (estimated cost of actual data collection)
<b>MM Data Analysis/Classification</b>	Analyzed 402 anomalies	21 minutes/anomaly  \$42/anomaly  \$18,014

### 8.1 COST DRIVERS

The primary cost considerations associated with the selection and broad implementation of advanced geophysics and classification technologies are:

- Cost of data collection with advanced sensor arrays (primarily labor, per diem, and equipment rental/repair);
- Cost of data processing, analysis, and anomaly classification (primarily labor); and
- Cost savings associated with reduction in number of anomalies requiring intrusive investigation (primarily labor, per diem, and equipment rental).

### 8.2 COST BENEFIT

The primary driver for developing advanced geophysics and classification technologies is to reduce the total cost associated with executing munitions responses. DoD recognizes that a large portion of the munitions response budget is and will be spent excavating and removing harmless metal fragments and non-munitions-related metal from MRSs. The implementation of advanced geophysics and classification has been demonstrated to reduce the total number of anomalies requiring intrusive investigation (i.e., excavation) by 60% to 90% in demonstration/validation projects. For advanced geophysics and classification to be broadly employed, these technologies must cost less to implement than the intrusive investigations that would be avoided by their implementation.

## 9.0 IMPLEMENTATION ISSUES

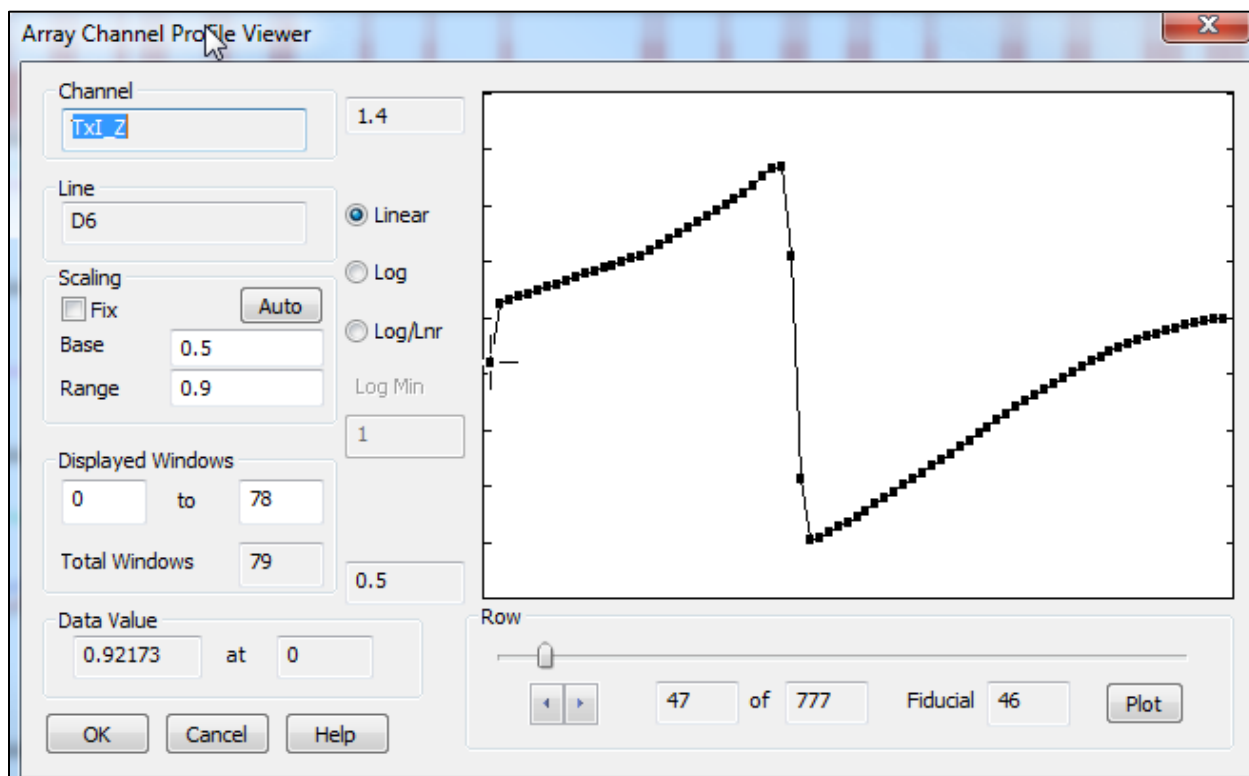
The MM advanced geophysical sensor and advanced data analysis methods in a production environment were used to characterize MEC hazards at the Silver Wings Golf Course Complex. Because URS' role in the Live Site Demonstration Program is to evaluate the implementation of these advanced sensors and classification methods from the perspective of a large-scale MMRP production company, URS documented issues/recommendations that will support implementation on an industry-wide scale.

### 9.1 ADVANCED GEOPHYSICAL SENSOR ARRAYS

#### 9.1.1 Transmitter Issues

URS was able to achieve high rates of production for both cued and dynamic data collection, including averages of over 300 cued anomalies per day (723 in two days) and more than 1 acre per day during dynamic collection. However, the field effort was dominated by equipment problems specific to the MM as four transmitter boards failed over the course of the field effort.

The first transmitter board failure occurred during the first day of data collection. Normal field operating procedures did not indicate a problem with the transmitter, but data analysis showed that the transmitter waveform was incomplete and did not reach the nominal peak transmitter current (see Figure 7). After collecting several days of data, the transmitter stopped completely.



**Figure 7. Fort Rucker MM Waveform**

A replacement MM electronics box was sent to the site, which allowed collection of 407 cued anomalies in the Demonstration Area and 4.4 acres of dynamic data on Fairway #6. Prior to collecting additional cued anomalies in Fairways #1, #6, and #9, the MM electronics box would

not turn on. While troubleshooting this issue, the field team connected the MM AC power supply to a battery that was powering the Inertial Measurement Unit (IMU). This resulted in 110V power from the inverter/battery shorting back through the IMU cable to the common ground on the battery, damaging the transmitter board within the MM electronics box.

The original MM electronics box was returned to the site from the manufacturer after 8.5 days of down time. Prior to data collection, the system continued to have transmitter issues, along with intermittent issues of one receiver not recording reasonable data during field checks. The field team partially disassembled the electronics box at the direction of Geometrics and replaced two damaged ribbon cables within the box. This is a known issue that Geometrics plans to resolve in later versions of the system – the ribbon cables are routed across two beveled metal corners that can cut into the relatively fragile cables over time. Replacing the ribbon cables resolved the receiver issue, but did not resolve the issues with the transmitter. This system was returned to Geometrics without collecting any new production data. After three days without an issue, the transmitter ceased transmitting prior to the morning tests on the fourth day. With only one additional day planned for data collection, the decision was made to end the survey.

While the cause for one of these failures was identified, the cause of the other transmitter board failures remains unknown. After the second transmitter board issue, each device was powered using a separate battery/power supply to avoid any potential issues with shorting back to a common ground.

#### 9.1.2 Standard Configuration for MetalMapper

MM acquisition was generally straightforward and proceeded at a quick pace once when the equipment was operating as designed.

URS developed a custom mount for attaching the MM on a fork attachment to a skid-steer, tracked bobcat. This configuration proved effective in generating high production rates and minimizing impact to the golf course.

## 10.0 REFERENCES

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## Appendix A: POINTS OF CONTACT

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